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SUMMARY

Axial-load fatigue tests were conducted on notched and unnotched sheet specimens of PH 15-7 Mo stainless steel in Condition TH 1050. Fatigue lives at three mean stresses at ambient temperature (approx. 80° F) and at 500° F were determined throughout the lifetime range from 10^2 to 10^7 cycles. A special furnace incorporating guide plates is also described.

A 500° F environment increased the fatigue limit but reduced the fatigue strength at short lifetimes. An effect of cyclic frequency was noted.

INTRODUCTION

Interest in the elevated temperature properties of high-strength materials for flight vehicles is increasing as supersonic speeds become more commonplace. The ability to maintain strength under elevated temperature conditions joins the high strength-density ratio as a prime material requirement. One of the important strength properties for vehicles subjected to continuously varying loads (such as those loads encountered by any vehicle traveling in the atmosphere) is the fatigue strength. Although some fatigue testing has been done on various materials at elevated temperatures, no concentrated body of systematic data is available for a modern high-strength material at more than one condition of fatigue loading and temperature throughout the lifetime from a few hundred cycles to 10^7 cycles.

This report presents the results of fatigue tests on PH 15-7 Mo stainless steel in Condition TH 1050 at three mean stresses and at two temperatures, ambient temperature (approx. 80° F) and 500° F. The elevated temperature might be experienced by the main wing structure of an aircraft traveling at a speed three times that of sound at an altitude above 35,000 feet. Both notched and unnotched specimens were investigated. The notched specimen used in this investigation (elastic stress concentration factor equal to 4) was considered to have fatigue properties approximately equal to those of good contemporary aircraft wing structures made of aluminum alloys. Material in sheet form was used because it represents much of an aircraft's structure. Unnotched specimens were investigated to provide a basis against which to evaluate notch effects.

A special furnace incorporating graphite guide plates to prevent buckling of thin sheet specimens under compressive loads is described.

SYMBOLS

E	modulus of elasticity, ksi
e	permanent tensile elongation in given gage length, percent
H_F	ratio of fatigue limit at any temperature to that at ambient temperature for similar specimens tested at same mean stress
K_F	stress concentration factor effective in fatigue (ratio of fatigue limit of unnotched specimens to that of notched specimens at same local mean stress)
K_N	stress-concentration factor corrected for size effect
K_T	theoretical stress-concentration factor
N	life of fatigue specimen, cycles
R	ratio of minimum stress to maximum stress during fatigue load cycle
S_{max}	maximum stress during a fatigue load cycle, ksi
S_{mean}	mean stress, ksi
S_u	static ultimate tensile strength, ksi
S_y	static yield stress in tension, 0.2-percent offset, ksi
ρ	radius of a notch, in.
ρ'	Neuber material constant, in.
ω	flank angle of a notch, radians

SPECIMENS, APPARATUS, AND PROCEDURE

Specimens

The specimen configurations, shown in figure 1, were machined from nine sheets of PH 15-7 Mo stainless steel, all produced from a single heat. The sheets were nominally 36 by 96 by 0.025 inches. The sheets were first sheared to oversize specimen blanks approximately 0.1 inch larger than the finished dimensions. A total of eight tensile specimen were fabricated from four locations in each sheet. The specimen blanks were stamped for identification and these designations are used in the tables of results.

The as-received annealed material (Condition A) proved to be tough and gummy and tended to produce large machining burrs. Therefore, before machining, specimen blanks were heat-treated according to manufacturer's recommendations for Condition TH 1050, which are:

(1) Clean with solvent

(2) Scrub mechanically with mild abrasive liquid cleaner

(3) Rinse with warm water and dry

(4) Heat to 1,400° F (±25° F); maintain temperature for 90 minutes

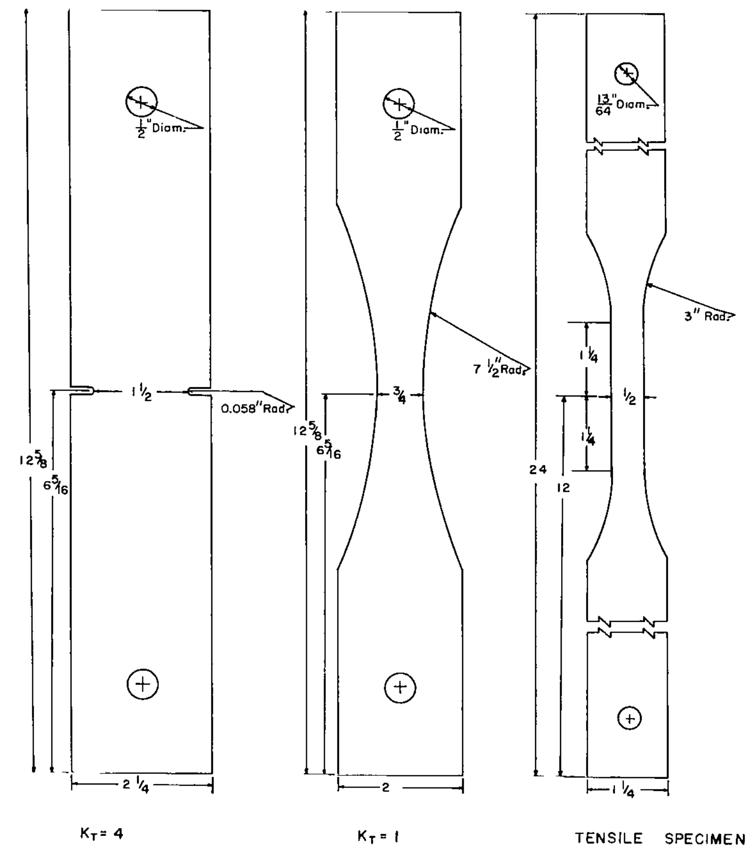

Figure 1.- Sheet specimen configuration. All dimensions are in inches unless otherwise noted.

(5) Cool to 60° F (+0°, -10° F); maintain temperature for 30 minutes

(6) Heat to 1,050° F (±10° F); maintain temperature for 90 minutes

(7) Air-cool to room temperature

While at elevated temperature, the blanks were in an argon atmosphere.

Each heat-treated batch of about 40 blanks was spot checked for the correct Rockwell R_C of 44. Variations in hardness were found to range from $R_C = 44$ to $R_C = 46$.

All blanks were first machined along the straight edges. Machining speeds were chosen to produce a clean-cut surface with a minimum amount of burrs. Throughout the machining process every effort was made to retain an unmarred specimen surface.

The blanks for unnotched fatigue specimens were stacked approximately six at a time and mounted in the headstock of a lathe. The radius was cut at 14 rpm. The final cut in the radius was 0.001 inch deep. The sharp corners at the machined radii were beveled by hand to remove any burrs which may have been formed. The beveling tool was No. 320 emery cloth backed by a block of wood having a radius slightly smaller than that of the specimen. The resulting bevel was approximately 0.003 inch across at an angle of 45°.

The blanks for the notched specimens were clamped in stacks of 10 in an automatic-feed drill press. The stress raisers in the notched specimens were formed by drilling with successively larger drills until the desired radius was obtained. The three final drill diameters were 0.110 inch, 0.113 inch, and 0.116 inch. The first two of these drills were guided with a bushing but the last drill was not. Rotational speed was 950 rpm and feed was 15/64 inch per minute. The drills were lubricated continuously and a new drill was used for each stack. The notches were completed by slotting from the edge with a 3/32-inch-wide milling tool. The corners at the notch radii were beveled by using a cone of rubber-abrasive composition which was chucked in a drill press and rotated at 3,000 rpm. Each specimen was handheld lightly against the cone until the resulting bevel was approximately 0.003 inch across at an angle of 45°.

The results of the beveling technique for both notched and unnotched specimens were individually checked with a 5-power magnifying glass and the specimens were spot checked for flaws and residual burrs with a 60-power stereo microscope.

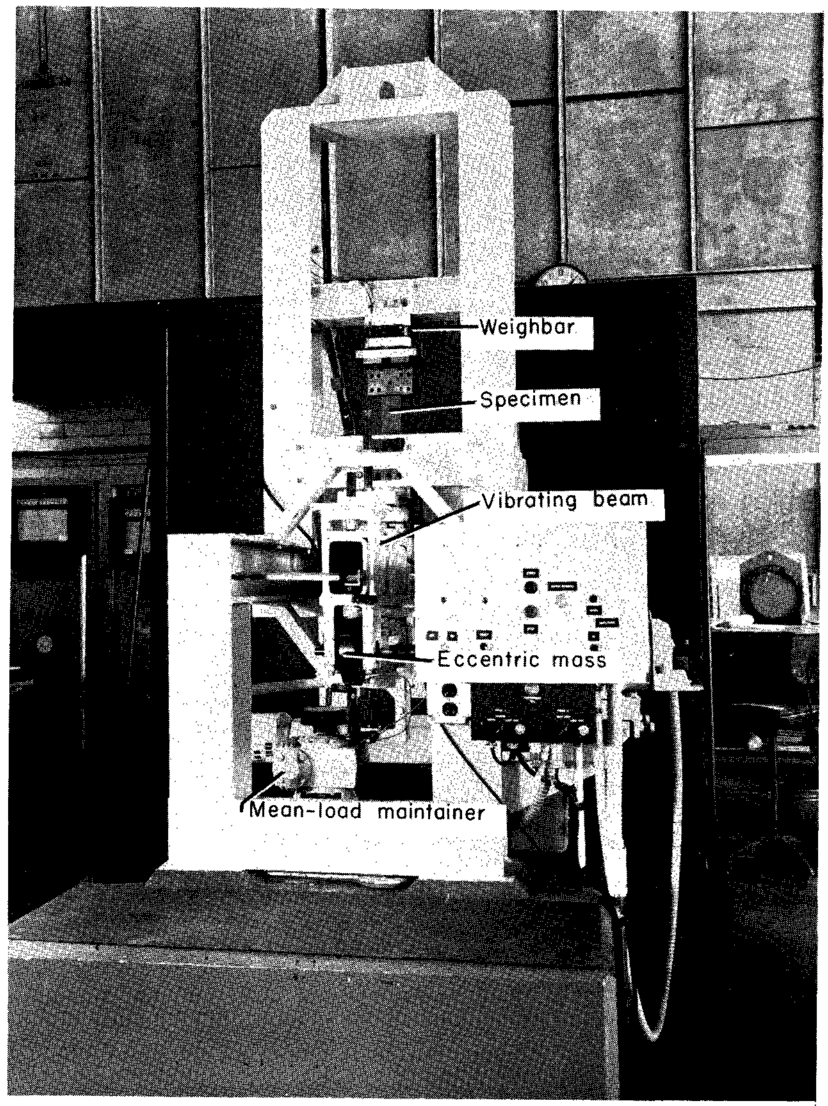

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Figure 2.- Subresonant axial-load fatigue testing machine.

Testing Machines and Load Measuring Equipment

Elevated temperatures resulted in dimensional changes in both machine and specimen. Although the specimen temperature was held constant throughout the test and was not a problem in load control, the temperature of the more massive machine structure slowly increased in the vicinity of the furnace. The resulting dimensional changes caused changes in the mean load. An automatic mean-load maintainer was developed to correct this problem and it was added to one of the two fatigue testing machines. The machine was a subresonant type operating at 1,800 cpm and is described in reference 1. Figure 2 presents a photograph and figure 3 shows a schematic of the same machine. The mean-load maintainer consisted of a gear motor in conjunction with an indicating potentiometer (fig. 3). The potentiometer sensed the mean load and signaled the gear motor to drive the loading beam in the proper direction whenever the error exceeded 0.2 percent of the weighbar capacity. The described apparatus is capable of compensating for creep deformation also.

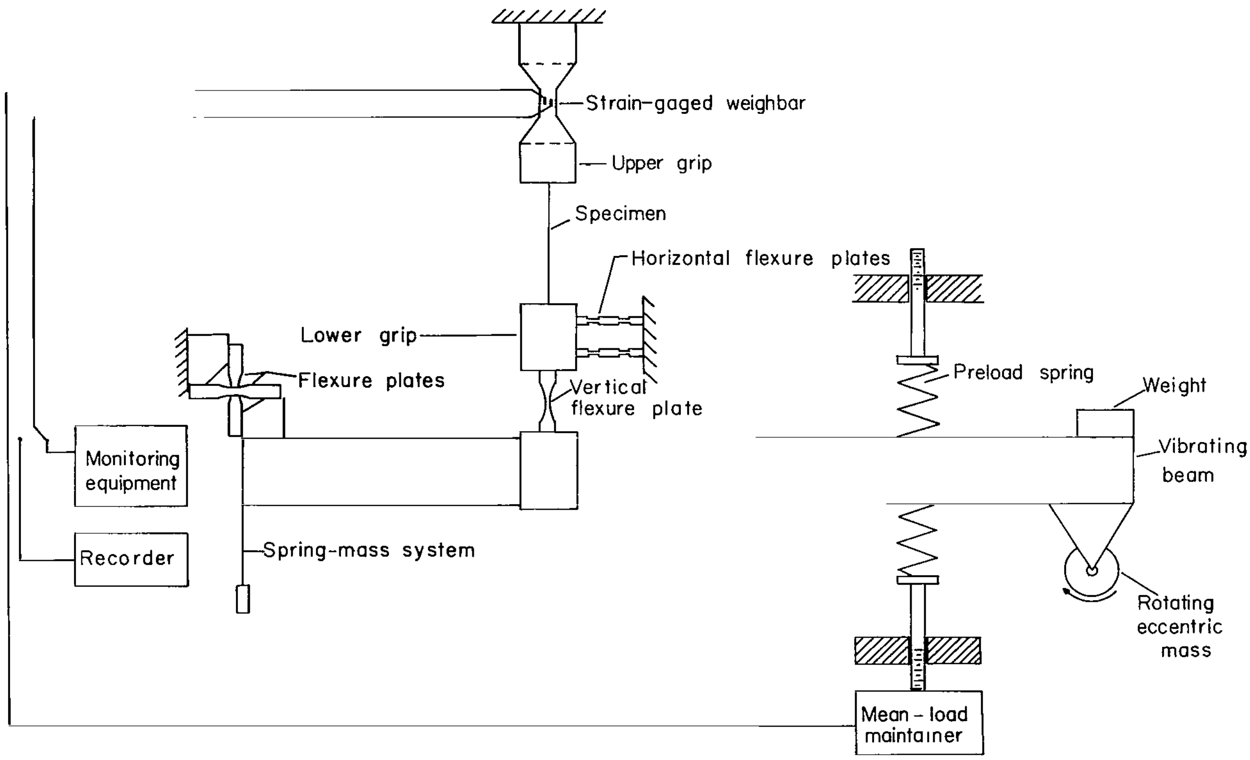

Figure 3.- Schematic of subresonant fatigue testing machine showing mean-load maintainer.

The second type of machine was hydraulically operated and pilot-valve controlled at a rate of approximately 24 cpm. A photograph of this machine appears in figure 4 and a schematic is shown in figure 5. Loads were applied in a horizontal direction by a hydraulic piston connected to one end of the specimen. The other end of the specimen was attached to a 10,000-pound-capacity

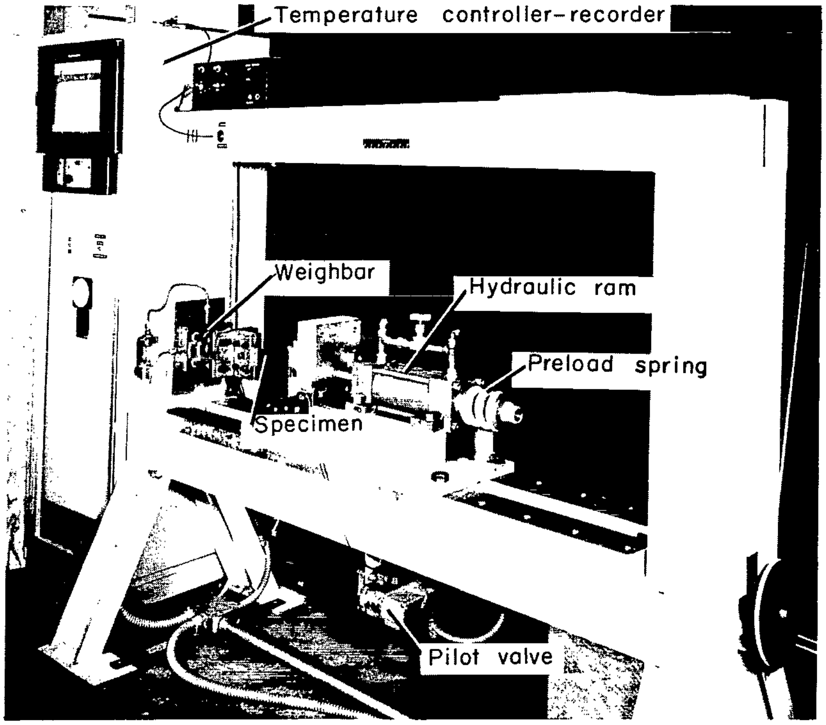

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Figure 4.- Hydraulic fatigue testing machine.

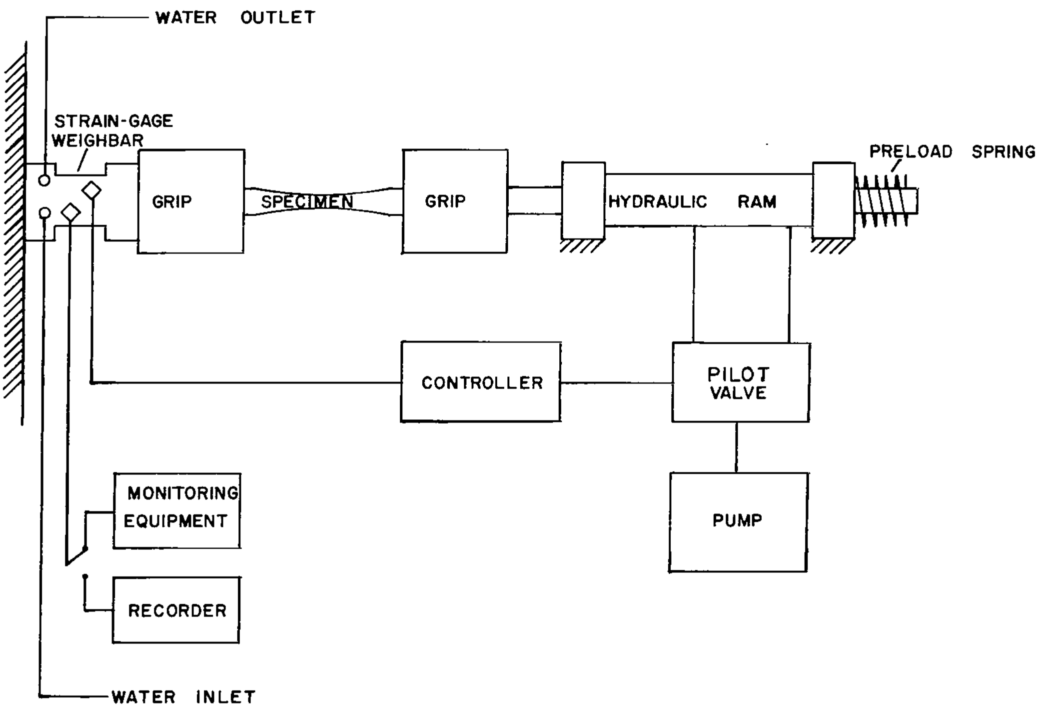

Figure 5.- Schematic of hydraulic fatigue testing machine.

cylindrical weighbar. One of the two bridges was used to supply a load signal to the hydraulic controller which, in turn, signaled the pilot valve, when required, to reverse load direction. The other bridge was used either to monitor the load on an oscilloscope or to record the load on a strip-chart recorder. All testing machines were periodically calibrated and maximum error in test loads was 1 percent of capacity.

Two types of water-cooled load transducers or weighbars were used in both types of machines. For low loads, a four-legged, 3,000-pound-capacity weighbar was employed (fig. 6). Cooling water was circulated through the base plates at about 0.3 gal/min and the entire assembly was wrapped with felt to eliminate the disturbing effects of drafts. Wire strain gages were cemented to the faces of the legs to form two independent bridges. An oscilloscope was used to monitor the loads on one bridge, and the other bridge was used to provide an input signal to the mean-load maintainer.

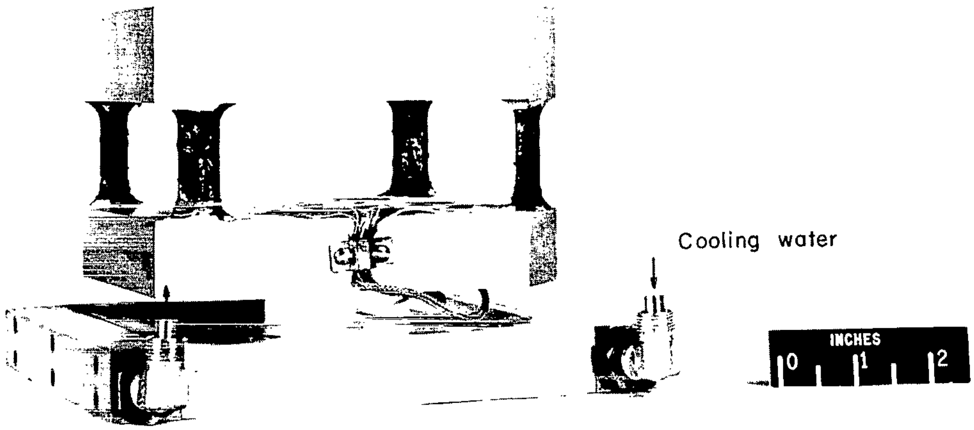

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Figure 6.- Water-cooled 3,000-pound-capacity weighbar.

For high loads, a 10,000-pound-capacity weighbar having the shape of a hollow cylinder was used (fig. 7). Wire strain gages were cemented to the exterior surfaces of the cylinder at the reduced-thickness circumferential neck to form two independent bridges. These bridges had the same function as those on the 3,000-pound-capacity weighbars. For high temperature investigations, cooling water was circulated at about 0.3 gal/min through the interior to provide a stable temperature environment for the strain gages. These weighbars were also wrapped with felt.

Furnace

The furnace is shown in detail in figure 8. It was designed to supply heat and to prevent buckling under compressive loads by acting as a lateral

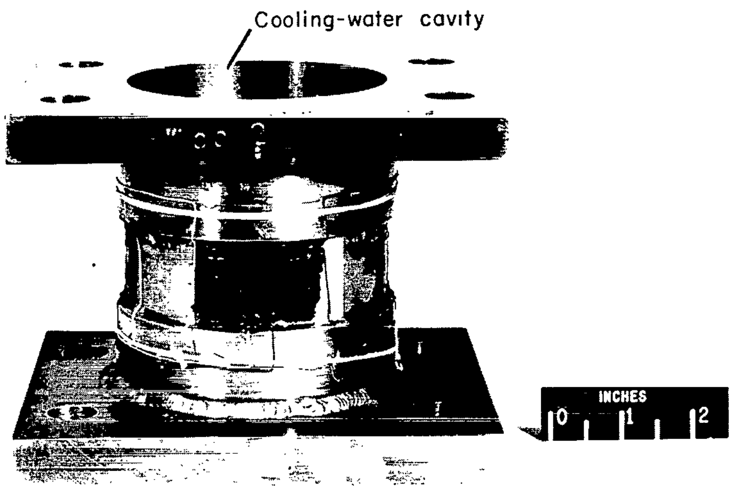

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Figure 7.- Water-cooled 10,000-pound-capacity weighbar.

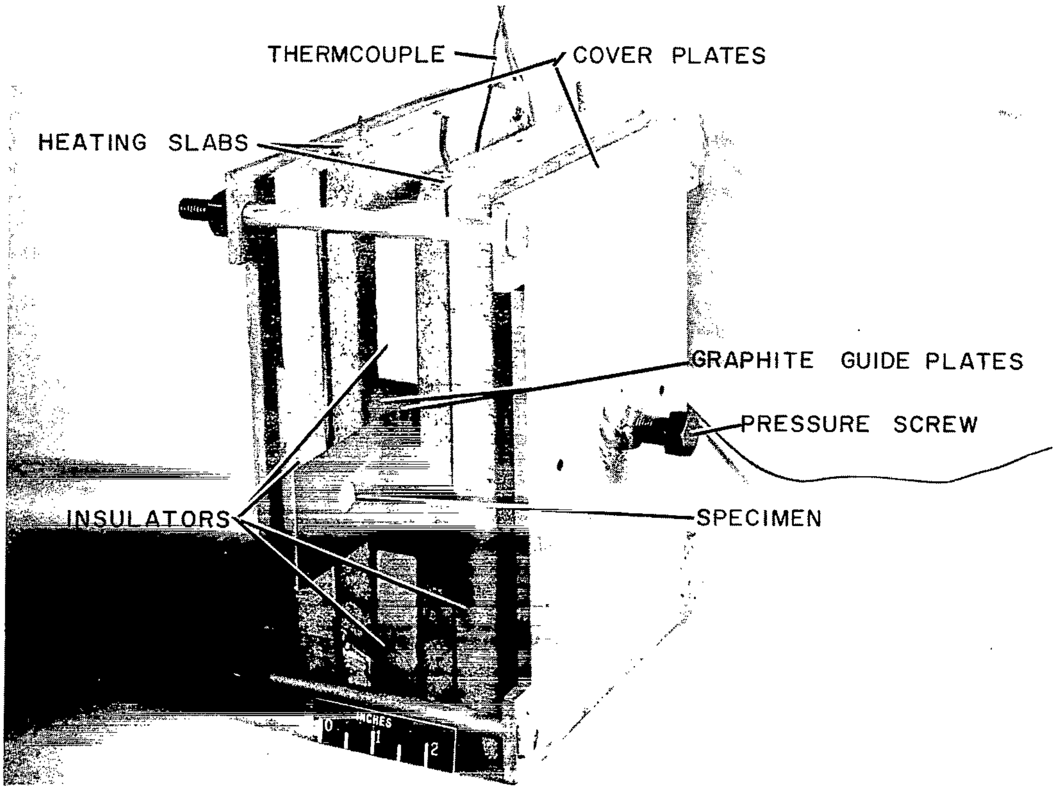

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Figure 8.- Detail of ceramic slab heater.

support for the specimens. Immediately adjacent to the specimen during a test are two graphite plates, each 1/2 inch thick. Graphite was chosen for the guide-plate material because it does not lose its strength at elevated temperatures and also has lubricating qualities.

Lateral compressive force, acting through steel plates, was applied to the specimen by a pair of machine screws on either side of the furnace. The threads were well supplied with a high-temperature lubricant and carefully tightened to a uniform torque for each test.

The effect of guide-plate friction on fatigue life was investigated by conducting a few tests in which the lateral force was reduced. These tests were performed either by reducing the torque on the pressure screws to a value just sufficient to maintain physical contact or by placing shims between the graphite plates to reduce the clamping force. The effects are discussed in a subsequent section. Before every test the graphite plates were ground flat with the use of emery paper backed by a flat steel plate. Powdered molybdenum disulphide was applied to the graphite to enhance lubrication.

A metallographic examination of the material before and after exposure to graphite at 500° F for 96 hours revealed no evidence of metallurgical effects from prolonged exposure to hot carbon.

The graphite plates contained a chromel-alumel control thermocouple sheathed in a ceramic tube to minimize a-c pickup. The thermocouple was located at a point opposite the center of the specimen at the midthickness of the graphite plate. The difference between the temperature at this point and at the surface of the specimen was found to be less than 2° F.

The ceramic heating slabs were cutdown versions of replacement heating elements for a commercial oven. For this program, they were reduced to a length of 10 inches.

Power was supplied through a saturable reactor regulated by a temperature controller-recorder unit. For the 500° F tests, the continuous power needed was approximately 700 watts. Repeatability of temperature control was within ±2° F. Heat-up overshoot lasted no longer than 10 minutes and maximum overshoot temperature was approximately 25° F.

Procedure

Tensile investigations.- The tensile specimens shown in figure 1 were used for both ambient and 500° F static tests. Stress-strain curves were autographically plotted with an X-Y plotter. A 2,400-pound-capacity load cell sensed load for both the 500° F and ambient temperature tests. The strain sensor for the ambient tests was a post-yield type of wire strain gage cemented to one face of the specimen. Such gages are not reliable beyond yield strain at 500° F; therefore, a mechanical extensometer was used at elevated temperatures (fig. 9) for transferring the elongation from marks 1 inch apart in the specimen to a pair of differential transformers. Their output was then delivered to the X-Y recorder which had a load sensitivity of 20 ksi per inch and a

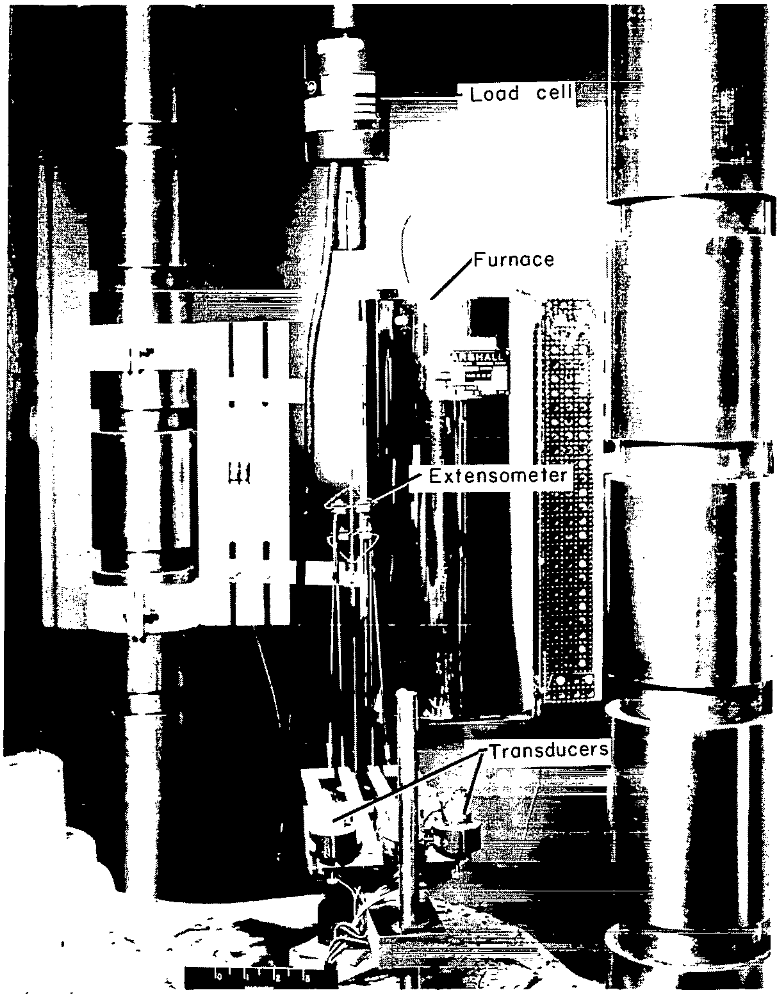

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Figure 9.- Elevated-temperature tensile-test setup.

strain sensitivity of 1.0 percent per inch. Straining rate was approximately 0.005 per minute for the elastic portion. After yield, the straining rate was approximately 0.05 per minute. Pretest heat exposure was approximately 1/2 hour. The maximum temperature variation in the test section was $\pm 3^{\circ}$ at 500° F.

Elevated-temperature fatigue investigations.- The specimens that were expected to survive 10^4 cycles at elevated temperatures were tested in the subresonant machines at 1,800 cpm and the specimens that were expected to have a short lifetime were tested in the hydraulic machines at 24 cpm. The "short-life" tests would have been very difficult to perform in the 1,800-cpm machines because the load magnitude would require adjustment after the machine had begun to cycle. Thus, for a specimen which would not fail, for example, until 600 cycles, the time available to adjust the load before failure would have been only 20 seconds. For at least half of the time, the test specimen would have been at an incorrect load. A number of tests were repeated at the same stresses in both the hydraulic and subresonant machines to investigate the effects of cyclic frequency on fatigue life.

An effort was made to allow equal heat soaking time prior to testing for all specimens. The usual time required to reach the desired temperature was about 20 minutes and tests were begun 10 minutes later.

After the load had been adjusted in the subresonant machines, the strain-gage bridge, which had, until then, been supplying a load signal to an oscilloscope monitor, was switched to a mean-load recorder. The procedure in the hydraulic machine was to switch over to a strip-chart recorder once the load had been set correctly. Upon fracture of the specimen, an interlock on all machines shut down the machine as well as the furnace.

Ambient-temperature fatigue investigations.- The ambient fatigue tests differed from the elevated-temperature tests in that no furnace was used and the guide plates were aluminum with oiled paper lining.

RESULTS AND DISCUSSION

Static Tensile Properties

The results of the static tensile tests at ambient temperature and 500° F are given in the following table together with the manufacturer's values for mechanical properties:

Source	Temperature, °F	Number of tests	S_u, ksi	S_y, ksi	e, percent	E, ksi
Present	Ambient	26	194 min. 201 av. 207 max.	193 min. 196 av. 201 max.	6.5 min. 7.4 av. 9.5 max.	29.0×10^3 min. 30.3×10^3 av. 31.2×10^3 max.
	500	18	171 min. 179 av. 182 max.	168 min. 173 av. 178 max.	[a]5.0 min. 5.7 av. 7.0 max.	22.0×10^3 min. 24.8×10^3 av. 30.0×10^3 max.
Manufacturer	80 500	---- ----	208 188	198 179	[b]7 ---------	---------- 26.7×10^3

[a]1-inch gage length.
[b]2-inch gage length.

The average stress-strain curve from many tests at each temperature is plotted in figure 10.

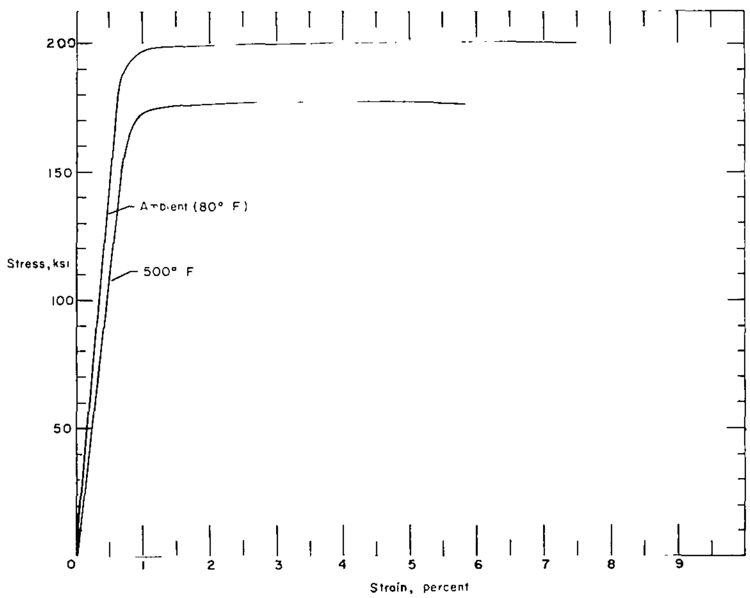

Figure 10.- Average stress-strain curve for PH 15-7 Mo in Condition TH 1050.

Fatigue Investigations

Temperature effects.- The results of the axial-load fatigue tests are given in tables I and II and are presented in figures 11 to 16 as S-N curves. The crossed points in figures 15 and 16 represent those tests in which the lateral clamping force was reduced by placing the shims between the graphite guide plates. In general, no consistent effect of guide-plate friction is evident.

The effects of temperature on the fatigue lives for all three mean stresses are illustrated in figures 17 to 19, which show the S-N curves for both unnotched ($K_T = 1$) and notched ($K_T = 4$) specimens. A useful quantity for describing the effect of temperature on the fatigue limit might be the ratio of the fatigue at any temperature to that at ambient temperature (called H_F). Deleterious temperature effects would result in a value for H_F of less than one; a value of H_F greater than one would mean a helpful effect. For the present investigation, values of H_F were 1.19, 1.11, and 1.09 for unnotched specimens at 500° F for mean stresses of 0, $33\frac{1}{2}$, and 67 ksi, respectively. Only the range of lifetimes greater than about 10^4 cycles is shown. The results were similar for all three mean stresses; the elevated temperature decreased the fatigue life at high stresses and increased the life at low stresses. This behavior might be due to a healing process mobilized on a microscopic scale by the elevated temperature and which tends to retard the accumulation of fatigue damage. The temperature-caused reduction in static strength depressed the low-cycle portion of the S-N curve. But for lower stresses near the fatigue limit, the healing effect overrode the weakening effect of the elevated temperature. The S-N curves for the two temperatures cross at a life of approximately 250,000 cycles for $K_T = 1$ and, depending on mean stress, the curves cross from 70,000 to 700,000 cycles for $K_T = 4$. It appears, from the viewpoint of fatigue damage, that a temperature of 500° F would be beneficial to PH 15-7 Mo Condition TH 1050 for stresses near the fatigue limit.

Behavior similar to that just described has been observed for other materials. For example, in reference 2, it is reported that the fatigue limit for an age-hardenable nickel-chromium alloy increases as the temperature rises from ambient temperature to approximately 1,100° F. Reference 3 contains results of elevated-temperature fatigue data on SAE 4340 steel heat-treated to 160,000-psi tensile strength. The fatigue limit of notched cylindrical specimens increased for a temperature increase of about 300° F at both $R = 0$ and $R = -1$.

Speed effect.- The effect of frequency on the fatigue life can be seen in figures 11 to 16. For the unnotched specimens tested at ambient temperature (figs. 11 to 13), the slow-speed tests resulted in shorter lives than did the high-speed tests for those stress levels where both speeds were employed (approx. 10^4 cycles). The results for the notched specimens tested at ambient temperature and for both unnotched and notched specimens tested at 500° F display no significant speed effect, although some tendency toward shorter lives can be found in certain plots for the slower frequency. This behavior is

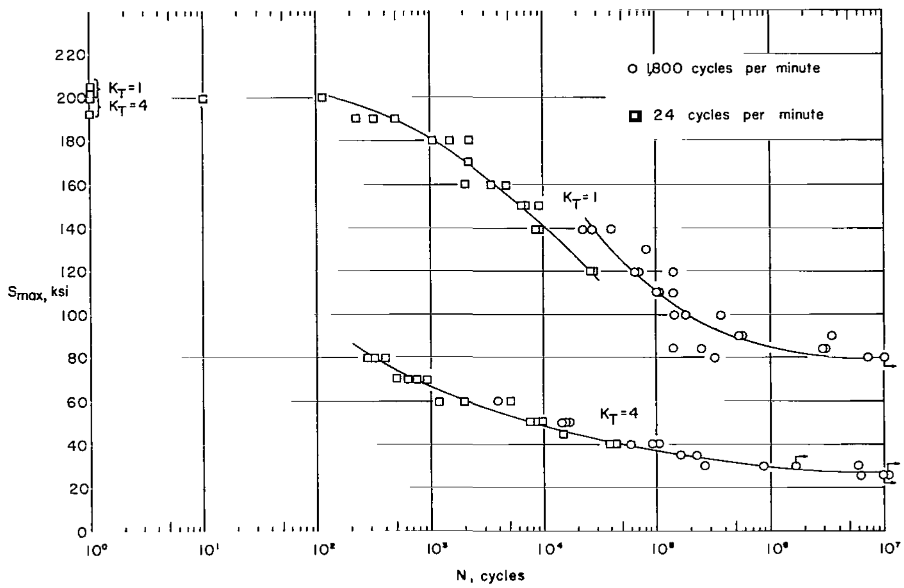

Figure 11.- Results of axial-load fatigue tests on notched and unnotched PH 15-7 Mo stainless-steel sheet specimens in Condition TH 1050 at ambient temperature with $S_{mean} = 0$.

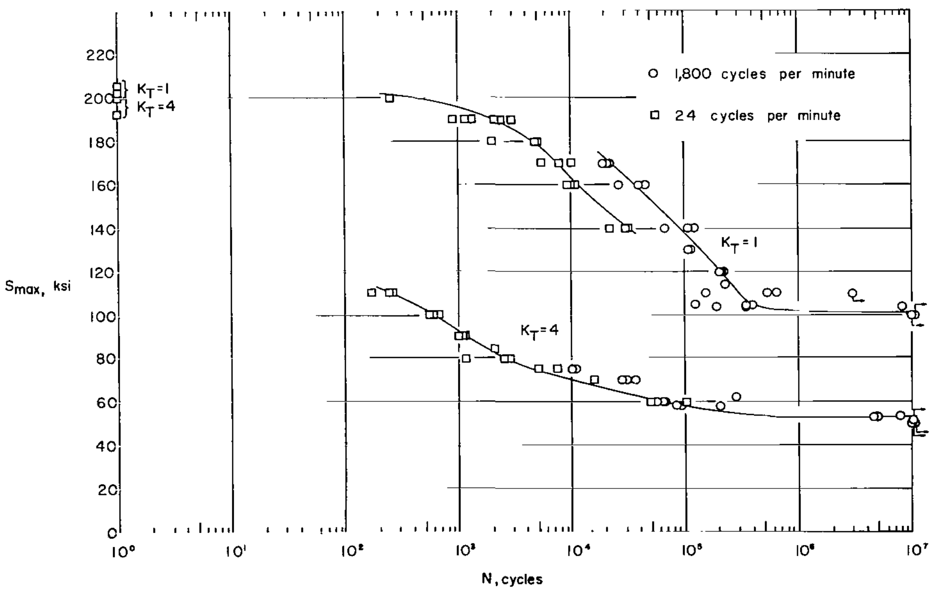

Figure 12.- Results of axial-load fatigue tests on notched and unnotched Ph 15-7 Mo stainless-steel sheet specimens in Condition TH 1050 at ambient temperature with $S_{mean} = 33\frac{1}{2}$ ksi.

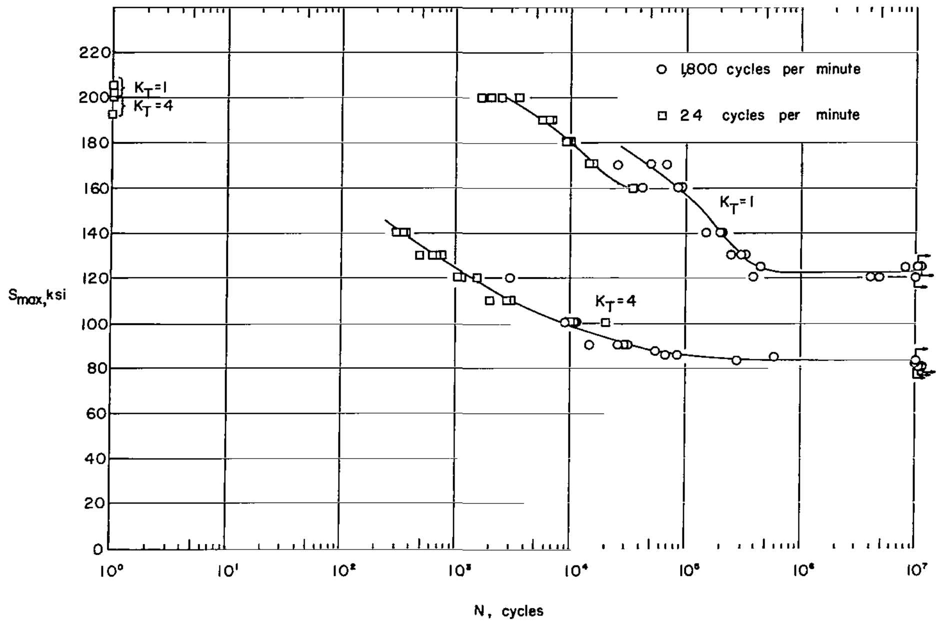

Figure 13.- Results of axial-load fatigue tests on notched and unnotched PH 15-7 Mo stainless-steel sheet specimens in Condition TH 1050 at ambient temperature with S_{mean} = 67 ksi.

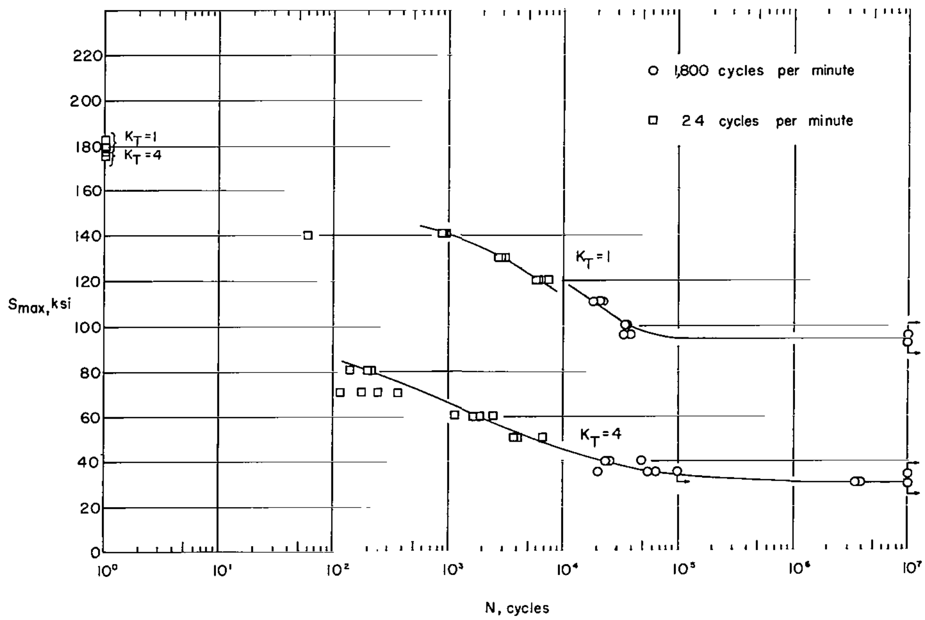

Figure 14.- Results of axial-load fatigue tests on notched and unnotched PH 15-7 Mo stainless-steel sheet specimens in Condition TH 1050 at 500° F with S_{mean} = 0.

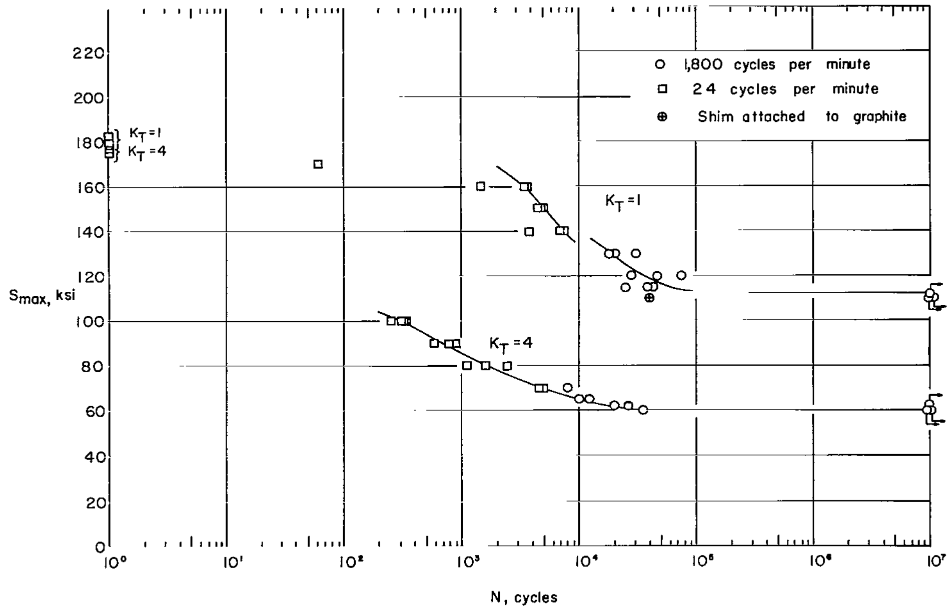

Figure 15.- Results of axial-load fatigue tests on notched and unnotched PH 15-7 Mo stainless-steel sheet specimens in Condition TH 1050 at 500° F with $S_{mean} = 33\frac{1}{2}$ ksi.

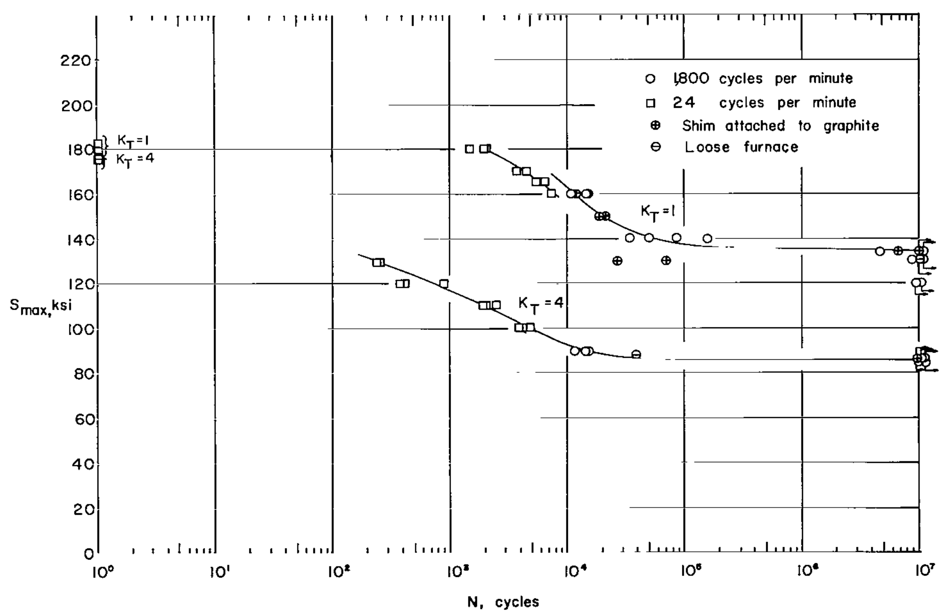

Figure 16.- Results of axial-load fatigue tests on notched and unnotched PH 15-7 Mo stainless-steel sheet specimens in Condition TH 1050 at 500° F with $S_{mean} = 67$ ksi.

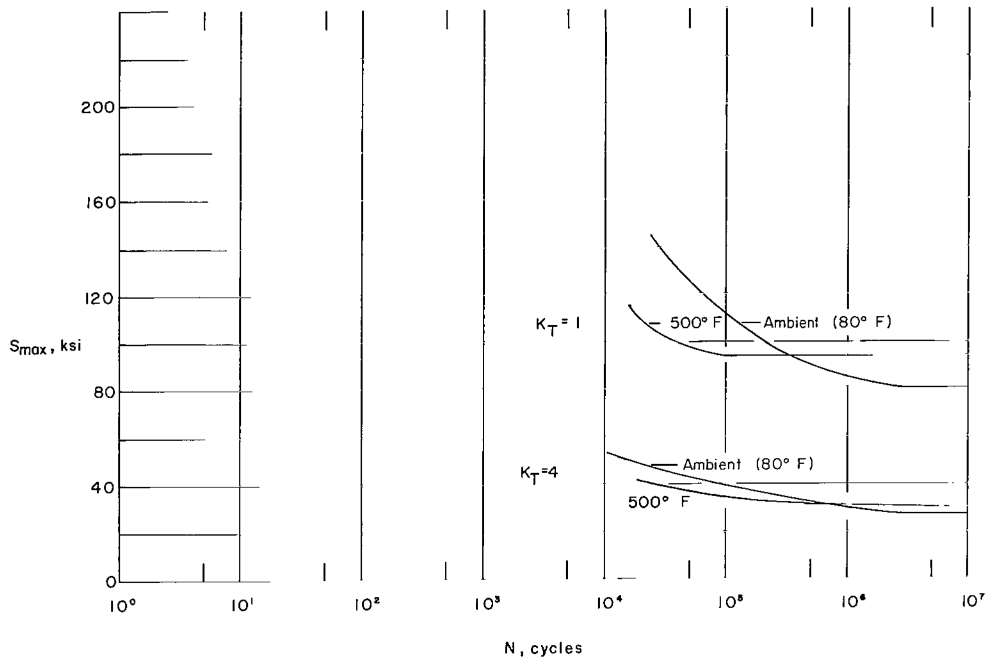

Figure 17.- Temperature effect on PH 15-7 Mo in Condition TH 1050 with $S_{mean} = 0$.

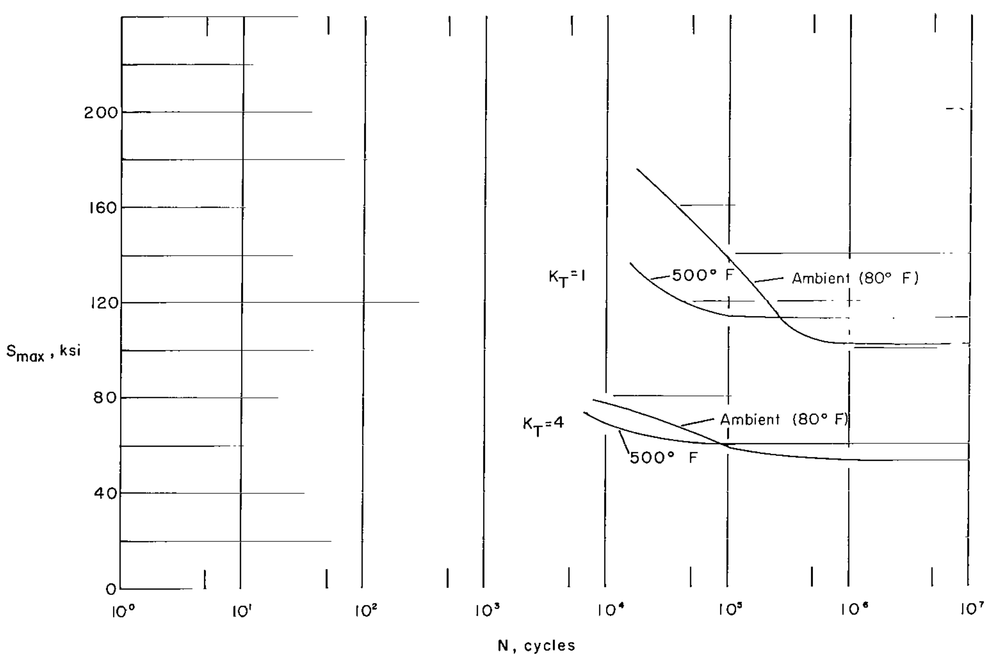

Figure 18.- Temperature effect on Ph 15-7 Mo in Condition TH 1050 with $S_{mean} = 33\frac{1}{2}$ ksi.

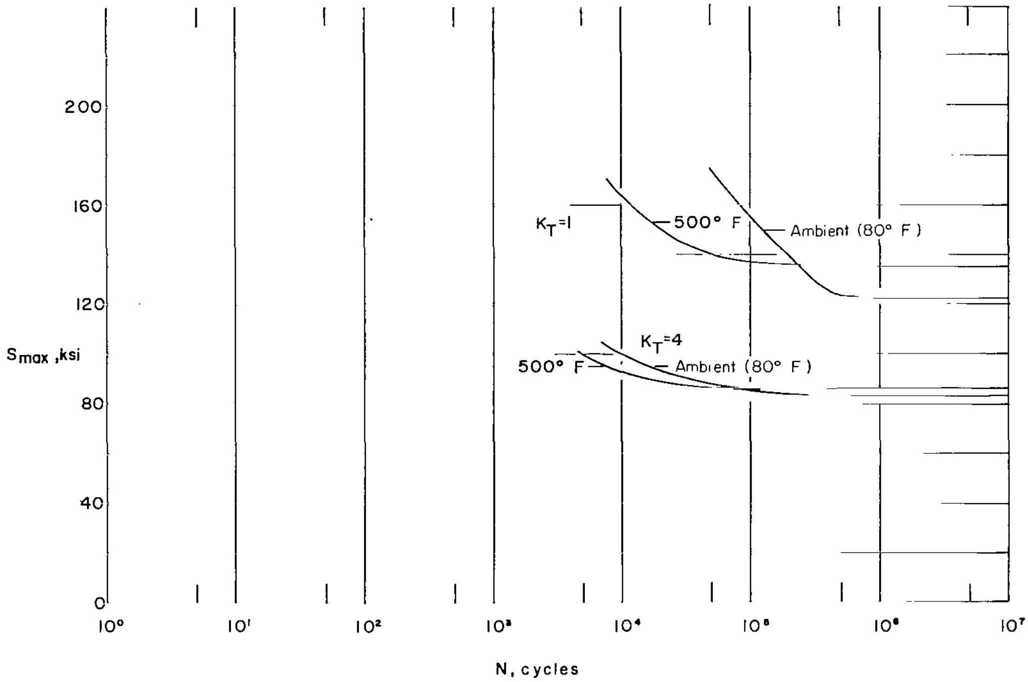

Figure 19.- Temperature effect on Ph 15-7 mo in Condition TH 1050 with $S_{mean} = 67$ ksi.

contrary to experience in that the addition of heat generally increases the time rate of damage under load for the higher stresses.

Published data for direct comparison of this material are not available but data in reference 4 show no frequency effect at speeds of 10 to 700 cpm at temperatures below 600° F for PH 15-7 Mo Condition RH 950. (The specimens were notched with a stress concentration factor K_T of 2.3.) These data would tend to corroborate the present findings for notched specimens.

Fracture surface.- There was nothing unusual about most of the fracture surfaces but a few isolated tests resulted in an extraordinary type of failure. A photograph of such a specimen, along with a photograph of a more normal failure, is shown in figure 20. The appearance resembles a ridge in the shape of a sine wave. This type of failure appeared sporadically and did not seem to be limited to any particular mean stress or temperature; also, the cause is unknown.

Stress concentration factor.- The stress concentration factor K_F, which is effective in fatigue, has been shown to be approximately equal to K_N at the fatigue limit for zero mean stress (ref. 5). The term K_N is the Neuber technical factor and was developed by Neuber as an engineering tool for use in design (ref. 6):

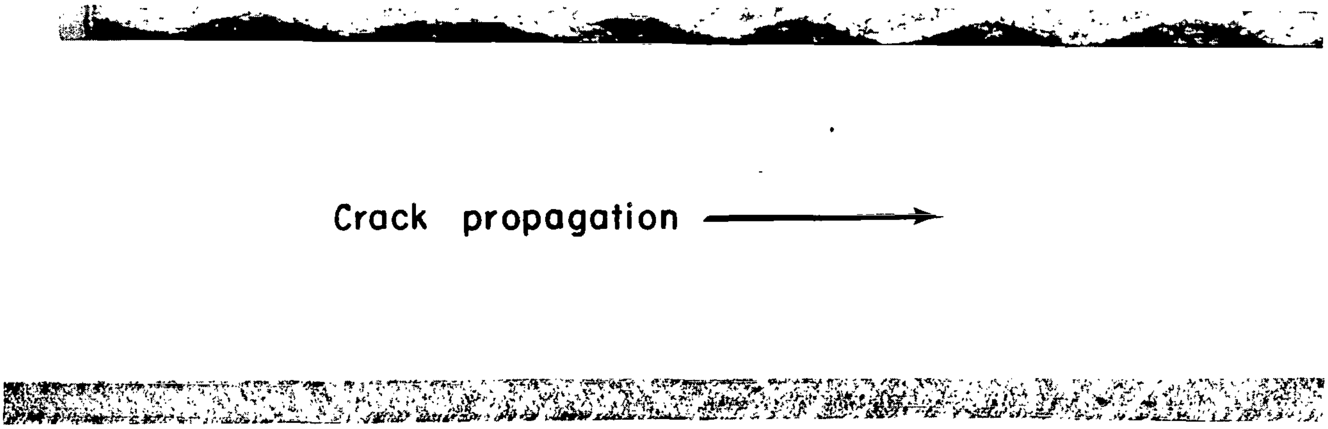

Figure 20.- Photographs of Ph 15-7 Mo fatigue specimens showing fracture surface of wavy and normal types of fatigue failure. (×10) L-64-3030

$$K_F = K_N = 1 + \frac{K_T - 1}{1 + \frac{\pi}{\pi - \omega}\sqrt{\frac{\rho'}{\rho}}}$$

where K_T is the theoretical geometrical stress concentration factor, ρ is the notch radius, and ω is the flank angle of the notch. The term ρ' is the Neuber factor which has a characteristic value for a given material at a given temperature and is found by adjustment to fit data. This constant ρ' is indicative of the notch sensitivity of the material; a large value means a low notch sensitivity. By using the values of K_F for unnotched and notched specimens at a mean stress of zero, ρ' is found to be 0.011 inch for both ambient temperature and 500° F. In reference 5, a relation is presented between ρ' and the tensile strength of carbon and low-alloy steels. For a strength equal to that of PH 15-7 Mo Condition TH 1050, ρ' for those steels would be in the neighborhood of 0.0002 inch. Thus, the present data demonstrate a lower notch sensitivity than would have been obtained in low-alloy steels of the same tensile strength. Reference 7 contains an extensive collection of aluminum-alloy fatigue data and gives a value for ρ' for aluminum alloys generally around 0.01 to 0.02, which is equivalent to that for PH 15-7 Mo. A structure made of PH 15-7 Mo might be expected to have notch sensitivity in fatigue similar to that experienced with contemporary aluminum structures.

Although the notch sensitivity in fatigue for PH 15-7 Mo Condition TH 1050 at 500° F was practically identical to that at ambient temperature as evidenced by similar values of K_F, this probably is not the case at very high temperatures - especially at temperatures where creep can have an important effect. That notch sensitivity can change markedly because of temperature elevation is illustrated by some fatigue data for a nickel-chromium alloy (ref. 8) at

1,700° F. At this temperature the fatigue limit for a notched specimen was actually greater than that for an unnotched specimen.

CONCLUDING REMARKS

Constant-amplitude fatigue tests have been performed on notched and unnotched specimens of PH 15-7 Mo Condition TH 1050 stainless steel at three mean stresses and at ambient temperatures and 500° F.

The results show that the fatigue limits are higher for 500° F than for ambient temperature. This fact indicates that fatigue damage is offset somewhat by the higher temperature. For lives less than approximately 100,000 cycles, the 500° F temperature decreases fatigue life. The lives of unnotched specimens tested at ambient temperature appear to be somewhat shorter when tested at 24 cpm as compared with those at 1,800 cpm in the region of 10^4 cycles.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., March 4, 1964.

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TABLE I.- RESULTS OF AXIAL-LOAD FATIGUE TESTS FOR PH 15-7 Mo CONDITION TH 1050 STAINLESS-STEEL SHEET SPECIMENS AT AMBIENT TEMPERATURE

(a) $S_{mean} = 0$; $K_T = 1$

Specimen	Maximum stress, S_{max}, ksi	Fatigue life, N, cycles	Frequency, cpm	Machine number
M8B 32	202	-----------	Static	
M8B 29	206	-----------	Static	
M4B 2	200	10	24	10
M4C 40	200	120	24	10
M4B 12	190	230	24	10
M4B 16	190	320	24	10
M4B 20	190	490	24	10
M6B 40	180	1,100	24	10
M1A 15	180	1,500	24	10
M1A 12	180	2,300	24	10
M5B 20	170	2,330	24	10
M1A 9	160	2,160	24	10
M1A 2	160	3,520	24	10
M1B 19	160	4,690	24	11
M1A 5	160	5,170	24	11
M6B 16	150	6,550	24	10
M4B 27	150	7,170	24	10
M6B 19	150	9,330	24	10
M4C 44	140	8,630	24	11
M5B 36	140	9,370	24	10
M1B 12	140	23,000	1,800	2
M2B 30	140	28,000	1,800	5
M2B 31	140	41,000	1,800	5
M2B 20	130	82,000	1,800	3
M4B 38	120	26,230	24	11
M4B 42	120	27,340	24	10
M2B 21	120	66,000	1,800	4
M5B 12	120	71,000	1,800	3
M5B 22	120	151,000	1,800	3
M4B 35	110	100,000	1,800	5
M4B 25	110	109,000	1,800	5
M4B 34	110	138,000	1,800	5
M5B 27	100	154,000	1,800	3
M1B 20	100	177,000	1,800	5
M5B 32	100	192,000	1,800	4
M5B 14	100	387,000	1,800	4
M1B 14	90	525,000	1,800	5
M1B 5	90	575,000	1,800	5
M1B 4	90	3,404,000	1,800	5
M2B 24	85	140,000	1,800	4
M6B 3	85	242,000	1,800	5
M5B 19	85	2,771,000	1,800	2
M2B 25	85	2,950,000	1,800	4
M2B 26	80	325,000	1,800	3
M1B 13	80	7,204,000	1,800	5
M1B 16	80	>10,700,000	1,800	4

(b) $S_{mean} = 33\frac{1}{2}$ ksi; $K_T = 1$

Specimen	Maximum stress, S_{max}, ksi	Fatigue life, N, cycles	Frequency, cpm	Machine number
M6B 21	200	240	24	10
M4B 9	190	900	24	10
M2B 11	190	2,240	24	10
M2B 12	190	2,400	24	10
M3B 21	190	3,030	24	11
M1B 22	180	2,000	24	10
M1A 6	180	4,700	24	10
M1A 11	180	5,000	24	10
M6B 32	170	5,440	24	11
M4C 3	170	7,830	24	10
M6B 35	170	10,130	24	11
M5B 37	170	19,000	1,800	5
M4C 43	170	21,000	1,800	5
M5B 16	170	22,000	1,800	5
M6B 7	160	9,270	24	10
M4C 42	160	10,150	24	11
M5B 23	160	12,180	24	11
M5B 3	160	26,000	1,800	5
M5B 5	160	39,000	1,800	5
M5B 8	160	44,000	1,800	5
M4B 41	140	22,710	24	11
M4B 34	140	30,000	24	11
M4B 41	140	30,650	24	10
M5B 1	140	66,000	1,800	5
M2B 9	140	113,000	1,800	5
M5B 6	140	129,000	1,800	5
M4B 24	130	107,000	1,800	5
M4B 22	130	111,000	1,800	5
M2B 2	120	209,000	1,800	5
M2B 1	120	210,000	1,800	4
M2B 3	120	221,000	1,800	4
M4B 43	114	225,000	1,800	5
M2B 4	110	138,000	1,800	4
M2B 5	110	525,000	1,800	5
M2B 8	110	658,000	1,800	4
M2B 7	110	>3,116,000	1,800	3
M2B 28	105	125,000	1,800	2
M2B 29	105	351,000	1,800	2
M2B 27	105	414,000	1,800	2
M6B 39	104	190,000	1,800	5
M4B 33	104	334,000	1,800	5
M6B 41	104	8,282,000	1,800	5
M5B 10	100	>10,200,000	1,800	5
------	100	>10,365,000	1,800	4

(c) $S_{mean} = 67$ ksi; $K_T = 1$

Specimen	Maximum stress, S_{max}, ksi	Fatigue life, N, cycles	Frequency, cpm	Machine number
M6B 23	200	1,640	24	10
M6B 1	200	2,050	24	10
M6B 10	200	2,460	24	11
M6B 34	200	3,590	24	10
M3B 23	190	5,500	24	10
M6B 33	190	6,490	24	10
M3B 22	190	6,780	24	11
M1B 18	180	70	24	11
M1A 1	180	9,100	24	11
M1A 4	180	9,300	24	10
M5B 25	180	9,630	24	11
M6B 8	170	14,180	24	11
M6B 5	170	14,830	24	10
M6B 9	170	15,490	24	10
M6B 31	170	25,000	1,800	2
M6B 6	170	49,000	1,800	2
M6B 36	170	68,000	1,800	2
M7B 43	160	34,160	24	11
M5B 28	160	41,000	1,800	4
M2B 15	160	84,000	1,800	4
M1B 24	160	94,000	1,800	4
M3B 26	140	148,000	1,800	5
M3B 32	140	207,000	1,800	5
M3B 27	140	212,000	1,800	5
M5B 41	130	241,000	1,800	5
M2B 37	130	306,000	1,800	5
M5B 43	130	335,000	1,800	3
M2B 36	125	434,000	1,800	5
M2B 34	125	8,596,000	1,800	5
M4B 36	125	>10,200,000	1,800	5
M2B 35	125	>11,000,000	1,800	3
M2B 41	120	392,000	1,800	5
M2B 40	120	4,082,000	1,800	5
M3B 34	120	4,867,000	1,800	5
M3B 37	120	>10,000,000	1,800	5

TABLE I.- RESULTS OF AXIAL-LOAD FATIGUE TESTS FOR PH 15-7 Mo CONDITION TH 1050 STAINLESS-STEEL SHEET SPECIMENS AT AMBIENT TEMPERATURE - Concluded

(d) $S_{mean} = 0$; $K_T = 4$

Specimen	Maximum stress, S_{max}, ksi	Fatigue life, N, cycles	Frequency, cpm	Machine number
M8C 2	193	-----------	Static	
M8C 38	200	-----------	Static	
M5C 11	80	270	24	11
M5C 12	80	330	24	11
M3C 29	80	430	24	10
M5C 5	70	500	24	11
M2C 23	70	652	24	10
M2C 24	70	665	24	10
M2C 45	70	764	24	11
M8C 10	70	940	24	7
M2C 26	60	1,258	24	10
M5C 10	60	2,000	24	10
M1C 4	60	4,000	1,800	2
M2C 27	60	5,012	24	10
M8C 4	50	7,570	24	6
M4C 21	50	8,280	24	10
M4C 32	50	9,320	24	11
M1C 7	50	14,000	1,800	2
M1C 1	50	15,000	1,800	2
M1C 2	50	16,000	1,800	2
M8C 44	45	16,028	24	6
M4C 36	40	37,590	24	10
M3C 27	40	44,170	24	10
M1C 3	40	58,000	1,800	4
M3C 18	40	91,000	1,800	2
M1C 8	40	111,000	1,800	4
M3C 7	35	162,000	1,800	2
M3C 1	35	232,000	1,800	2
M3C 12	30	258,000	1,800	3
M2C 29	30	854,000	1,800	2
M3C 14	30	2,342,000	1,800	4
M1C 9	30	5,187,000	1,800	3
M5C 30	26	6,220,000	1,800	5
M5C 1	26	>10,200,000	1,800	5
M5C 4	26	>11,142,000	1,800	2

(e) $S_{mean} = 33\frac{1}{2}$ ksi; $K_T = 4$

Specimen	Maximum stress, S_{max}, ksi	Fatigue life, N, cycles	Frequency, cpm	Machine number
M4C 19	110	180	24	10
M7C 30	110	240	24	11
M4C 34	110	250	24	10
M2C 31	100	547	24	10
M3C 10	100	560	24	11
M8C 13	100	560	24	7
M3C 9	100	617	24	10
M5C 2	90	1,000	24	10
M5C 3	90	1,100	24	11
M5C 6	90	1,100	24	11
M8C 26	85	2,280	24	7
M5C 7	80	1,200	24	10
M5C 8	80	2,500	24	11
M2C 28	80	2,800	24	10
M4C 20	75	5,170	24	10
M4C 37	75	7,360	24	11
M2C 37	75	10,000	1,800	2
M2C 38	75	11,000	1,800	2
M5B 31	70	17,630	24	10
M3C 32	70	27,000	1,800	2
M3C 17	70	31,000	1,800	2
M3C 33	70	36,000	1,800	2
M8C 29	62	284,000	1,800	5
M2C 34	60	49,970	24	10
M3C 20	60	55,000	1,800	2
M3C 16	60	65,000	1,800	2
M3C 15	60	67,000	1,800	2
M2C 14	60	103,000	24	10
M2C 42	58	85,000	1,800	5
M3C 6	58	94,000	1,800	5
M2C 39	58	210,000	1,800	5
M3C 34	55	4,391,000	1,800	2
M3C 36	55	4,732,000	1,800	2
M3C 11	55	7,616,000	1,800	2
M7C 14	$52\frac{1}{2}$	>10,200,000	1,800	5
M3C 31	50	>10,000,000	1,800	3
M3C 37	50	>10,000,000	1,800	3

(f) $S_{mean} = 67$ ksi; $K_T = 4$

Specimen	Maximum stress, S_{max}, ksi	Fatigue life, N, cycles	Frequency, cpm	Machine number
M2C 32	140	306	24	10
M3C 19	140	336	24	10
M2C 33	140	337	24	10
M8C 24	130	480	24	7
M3C 30	130	620	24	11
M3C 22	130	630	24	11
M3C 8	130	780	24	11
M2C 44	120	1,150	24	11
M4C 35	120	1,230	24	11
M2C 43	120	1,500	24	11
M1C 11	120	3,000	1,800	5
M7C 28	110	2,010	24	11
M2C 41	110	2,940	24	11
M2C 36	110	3,110	24	11
M1C 14	100	9,000	1,800	5
M2C 35	100	10,170	24	10
M1C 12	100	11,000	1,800	5
M1C 13	100	11,000	1,800	5
M2C 18	100	20,600	24	11
M2C 4	90	14,000	1,800	2
M1C 22	90	26,000	1,800	5
M2C 1	90	30,000	1,800	5
M1C 18	90	32,000	1,800	5
M8C 20	87	56,000	1,800	5
M6C 3	85	60,000	1,800	4
M2C 8	85	67,000	1,800	2
M2C 9	85	84,000	1,800	5
M2C 10	85	602,000	1,800	5
M8C 25	83	284,000	1,800	5
M8C 27	83	>10,000,000	1,800	4
M1C 10	82	>10,000,000	1,800	2
M1C 15	80	>10,000,000	1,800	5
M1C 17	80	>10,000,000	1,800	3

TABLE II.- RESULTS OF AXIAL-LOAD FATIGUE TESTS FOR PH 15-7 Mo CONDITION TH 1050 STAINLESS-STEEL SHEET SPECIMENS AT 500° F

(a) $S_{mean} = 0$; $K_T = 1$

Specimen	Maximum stress, S_{max}, ksi	Fatigue life, N, cycles	Frequency, cpm	Machine number
M8B 15	183	-----------	Static	--
M2B 44	180	-----------	Static	--
M4B 7	179	-----------	Static	--
M6B 22	140	60	24	11
M8B 4	140	891	24	10
M8B 6	140	915	24	10
M8B 21	140	923	24	10
M8B 36	130	2,855	24	10
M8B 35	130	2,926	24	10
M6B 24	130	3,190	24	11
M6B 27	120	5,840	24	11
M4B 19	120	6,000	24	11
M8B 40	120	7,363	24	11
M7B 44	110	18,000	1,800	3
M6B 28	110	21,000	1,800	4
M4B 28	110	22,000	1,800	3
M5B 11	100	35,000	1,800	4
M2B 14	100	35,000	1,800	4
M6B 18	95	34,000	1,800	3
M6B 7	95	38,000	1,800	4
M4B 39	95	>10,000,000	1,800	3
M5B 34	92	>10,000,000	1,800	3

(b) $S_{mean} = 33\frac{1}{2}$ ksi; $K_T = 1$

Specimen	Maximum stress, S_{max}, ksi	Fatigue life, N, cycles	Frequency, cpm	Machine number
M4B 30	170	60	24	10
M4B 5	160	1,550	24	10
M4B 32	160	3,570	24	11
M4B 31	160	3,720	24	11
M6B 38	150	4,410	24	10
M6B 13	150	4,500	24	11
M6B 38	150	4,700	24	10
M4B 10	140	3,700	24	10
M6B 29	140	7,000	24	10
M4B 3	140	7,400	24	10
M4B 8	130	17,000	1,800	4
M6B 42	130	21,000	1,800	3
M4B 17	130	31,000	1,800	3
M1A 3	120	28,000	1,800	3
M5B 4	120	47,000	1,800	4
M2B 10	120	74,000	1,800	4
M1A 7	115	25,000	1,800	3
M1A 10	115	38,000	1,800	5
M1A 8	115	43,000	1,800	3
M4B 23	112	>10,000,000	1,800	3
M2B 32	110	[a]40,000	1,800	3
M1B 1	110	>10,000,000	1,800	3
M4B 37	110	>10,000,000	1,800	3

(c) $S_{mean} = 67$ ksi; $K_T = 1$

Specimen	Maximum stress, S_{max}, ksi	Fatigue life, N, cycles	Frequency, cpm	Machine number
M4B 11	180	1,560	24	11
M6B 14	180	2,020	24	10
M6B 12	180	2,110	24	10
M6B 20	170	3,700	24	10
M4B 14	170	4,600	24	11
M6B 44	165	5,400	24	10
M4B 21	165	6,500	24	11
M4B 26	160	7,270	24	11
M2B 39	160	11,000	1,800	3
M5B 39	160	[a]13,000	1,800	4
M2B 38	160	14,000	1,800	4
M3B 30	160	15,000	1,800	4
M2B 14	150	[a]19,000	1,800	4
M2B 13	150	[a]22,000	1,800	4
M3B 25	140	34,000	1,800	4
M3B 29	140	51,000	1,800	4
M3B 31	140	87,000	1,800	4
M3B 24	140	168,000	1,800	3
M4B 15	134	4,617,000	1,800	3
M3B 9	134	[a]6,578,000	1,800	3
M4B 7	134	>10,000,000	1,800	3
M6B 20	134	[a]>10,000,000	1,800	4
M5B 40	130	[a]27,000	1,800	4
M5B 42	130	[a]70,000	1,800	4
M5B 44	130	8,682,000	1,800	4
M3B 35	130	>10,000,000	1,800	4
M4B 40	130	[b]>10,000,000	1,800	4
M3B 37	120	>10,000,000	1,800	4
M3B 36	120	>10,000,000	1,800	3

(d) $S_{mean} = 0$; $K_T = 4$

Specimen	Maximum stress, S_{max}, ksi	Fatigue life, N, cycles	Frequency, cpm	Machine number
M2C 14	183	-----------	Static	--
M2C 5	177	-----------	Static	--
M8C 16	175	-----------	Static	--
M8C 4	80	142	24	11
M8C 31	80	200	24	11
M8C 3	80	221	24	11
M8C 37	70	112	24	11
M8C 5	70	177	24	10
M8C 6	70	245	24	10
M8C 30	70	380	24	11
M6C 37	60	1,200	24	11
M7C 25	60	1,600	24	11
M2C 20	60	1,800	24	11
M5C 23	60	2,400	24	11
M5C 26	50	3,700	24	11
M7C 22	50	4,100	24	11
M2C 15	50	6,800	24	10
M3C 3	40	23,000	1,800	3
M3C 2	40	25,000	1,800	4
M6C 38	40	48,000	1,800	4
M5C 29	35	20,500	24	11
M7C 29	35	54,000	1,800	4
M5C 21	35	64,000	1,800	4
M7C 16	35	>100,000	24	11
M5C 24	34	>10,000,000	1,800	4
M3C 25	30	3,404,000	1,800	3
M3C 21	30	3,727,000	1,800	4
M2C 16	30	>10,000,000	1,800	4

(e) $S_{mean} = 33\frac{1}{2}$ ksi; $K_T = 4$

Specimen	Maximum stress, S_{max}, ksi	Fatigue life, N, cycles	Frequency, cpm	Machine number
M8C 14	100	255	24	10
M8C 22	100	300	24	10
M8C 39	100	315	24	10
M7C 32	90	600	24	10
M7C 15	90	800	24	10
M2C 19	90	800	24	10
M2C 12	90	900	24	11
M7C 26	80	1,200	24	10
M7C 31	80	1,600	24	10
M5C 28	80	2,400	24	10
M4C 18	70	4,500	24	11
M7C 27	70	4,900	24	10
M3C 23	70	8,000	1,800	3
M3C 24	65	10,000	1,800	3
M3C 26	65	13,000	1,800	3
M8C 45	62	20,000	1,800	3
M8C 17	62	26,000	1,800	3
M8C 41	62	>10,700,000	1,800	3
M3C 28	60	36,000	1,800	5
M3C 35	60	1,020,000	1,800	5
M5C 9	60	>10,000,000	1,800	4

(f) $S_{mean} = 67$ ksi; $K_T = 4$

Specimen	Maximum stress, S_{max}, ksi	Fatigue life, N, cycles	Frequency, cpm	Machine number
M8C 18	130	238	24	10
M8C 36	130	251	24	11
M8C 21	120	390	24	10
M8C 23	120	420	24	10
M7C 21	120	900	24	10
M7C 34	110	1,900	24	10
M7C 10	110	2,000	24	10
M2C 17	110	2,500	24	10
M5C 27	100	3,900	24	11
M7C 18	100	4,100	24	11
M7C 23	100	5,000	24	10
M2C 2	90	12,000	1,800	5
M2C 3	90	14,000	1,800	5
M2C 4	90	14,000	1,800	5
M7C 13	88	[b]39,000	1,800	3
--- --	87	>10,679,000	1,800	3
M1C 6	86	>10,000,000	1,800	5
M2C 7	85	>10,000,000	1,800	5
M8C 19	85	[a]>10,000,000	1,800	3
M2C 5	80	>10,000,000	1,800	5

[a]Shim attached to graphite guide plates.
[b]Loose furnace.

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